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Temperature measurements in a shock wave created by a cutting plasma torch.

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Abstract : This paper deals with the spectroscopic study of an oxygen plasma cutting torch. A particular attention is taken on the measurements in the shock wave created by this kind of configuration and an original method is presented for measuring temperature in this shock.

Introduction

Since ten year, cutting plasma processes try to rival with laser cutting systems. For this, a new plasma torch generation called "high energy density torch" [1] was developed by industrials in the middle of the nineties. This new generation of torch has very particular characteristics : a low current intensity (between 30 and 100A), a flat cathode, oxygen as plasma gas, very small nozzle diameter (around 1mm) and the plasma created is generally supersonic with the presence of a shock wave at the nozzle exit. Up to day engineering expertise based on observations of the cutting quality has allowed this process to progress. But now, more theoretical studies are needed for a better understanding of the arc behaviour. If some papers exist about "the traditional" plasma cutting systems [2][3], there are very few works about this new generation of torches[4]. This is probably due to the difficulties of making spectroscopic measurements in these cutting plasma especially in the wave shock zone.

In this communication, we purpose an original method for a spectroscopic study of this zone. Measurements are made on a torch commercialised by Air Liquide. We present first the studied configuration and the experimental set-up. After, the spectrum emitted by the plasma in the visible wavelengths is shown. The particular method is then proposed to determine the temperature and the electronic densities in the shock wave. Finally, measurement of the plasma temperature is proposed.

1 Experimental configuration

The system studied is an OCP150 torch. The diameter of the nozzle is equal to 1mm, the current intensity used for this paper is 60A. Oxygen is taken as plasma gas and injected through a swirl in top of a flat cathode situated in a pressure chamber. The arc discharges in air at atmospheric pressure. In a real cutting configuration, the metal piece to be cut is taken as anode and the distance between the nozzle exit and the workpiece is equal to few millimetres. With this short distance, spectroscopic measurements are difficult. Consequently, for practical considerations, the arc is transferred on the side of a rotating anode and stretched on 15mm. This configuration is presented on figure 1. It enables us to make spectroscopic measurements. An optical system collects the light emitted by the plasma on the entry of a THR1000 Jobin Yvon monochromator. The light intensity is converted in an electrical signal by a 1024x128 Hamamatsu photodiode matrix. The optical system gives a magnitude of 2 and enables to analyse any points of the plasma in the radial and axial directions. With 128 pixels, we can obtain all the light emitted by a section of plasma of 1.5mm height. Measurements were performed with an inlet pressure of 4.2atm.

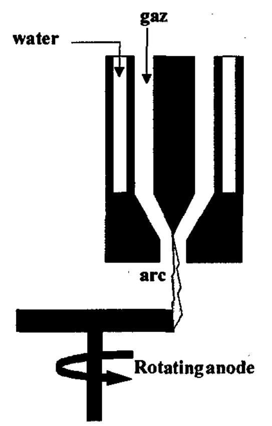

Figure 1 : Experimental configuration.

2 Spectral analysis of the light emitted by the arc

Before studying spectral emission of the plasma, an image of the arc created in the experimental configuration was obtained and enables us to situate the shock wave in an axial location between 0.5 and 2mm from the nozzle exit. This shock is due to the adaptation of the pressure in the chamber to the atmospheric pressure. Consequently, the light emitted on the axe of the plasma at 1mm from the nozzle was collected and the spectrum obtained is presented in figure 2. At low wavelengths, we can observe the presence of ionic lines of oxygen (between 4000 and 5000Å) whereas at upper wavelengths (6000-8500Å) only atomic lines are present. For spectroscopic analysis only the ionic line at 4647Å and atomic line at 6455Å are used. The line 6455Å is Stark widened

and can so be used for electronic densities determination[5].

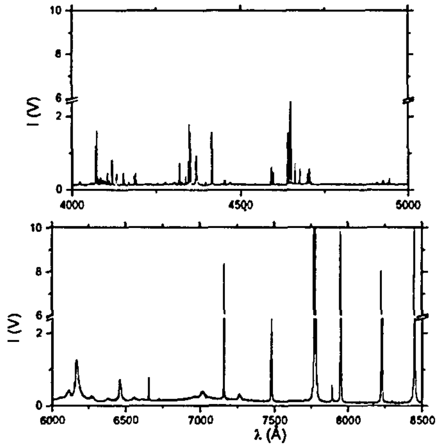

Figure 2 : Spectre of the light emitted by the arc in the shock zone.

3 Assumptions – method for the measure of the temperature

For spectroscopic measurements, we assume the plasma to be in LTE and to be optically thin for the wavelengths studied [6]. The local emissivity of the lines are determined from the Abel inversion. As the pressure of the plasma varies radially and axially and is unknown, the classical method of emission spectroscopy cannot be used. Instead, we purpose an iterative method for determining local temperature and local electronic densities :

-1- We assume a temperature T_0 and another $T_1=T_0+10K$.
-2- From the measurement of the ionic line intensity, and from the Boltzmann law, we determine the oxygen ion populations N^1_{O+} and N^0_{O+} at the respective temperature T_1 and T_0.
-3- From the experimental Stark broadening of the line 6455Å the electronic densities N^1_e and N^0_e at T_1 and T_0 are obtained.
-4- While $\left(N^1_{O+}-N^1_e\right)\cdot\left(N^0_{O+}-N^0_e\right)$ is positive, we increment by 10K T_0 and T_1 and go back on point 1 else the temperature sought is between T_0 and T_1.
This method does not depend on local composition and pressure and enables to determine the local temperature of the plasma. The electronic densities is also obtained.

4 Results

The field of temperature obtained between 0.5 and 2.1mm from the nozzle exit is presented in figure 3. We can quote the presence of local maximum of temperature on the axe. This maximum around 19400K is situated at the exit of the shock wave. It is due to the conservation of the energy in the fluid. Effectively, at this location, there is a stagnation point, velocities of the plasma decrease and so temperature increases in order to conserve the total energy of fluid. Radially, the temperature decrease very quickly from 19000K on the axe to 15000K at 0.5mm. This denotes the very fine diameter of the plasma flow for a such cutting configuration.

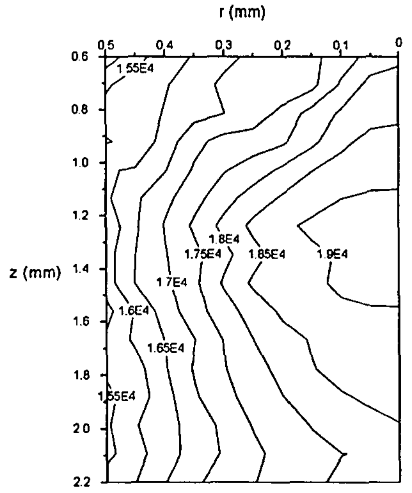

Figure 3 : Temperature (K) of the plasma in the shock wave zone.

Conclusion

A specific spectroscopic method for measuring temperature in the shock wave created by a cutting plasma torch is presented. This method, based on LTE consideration and electronic and ionic population measurements enables to estimate the local temperature of the plasma. A local maximum of the temperature equal to 19400K is fount on the axis.

ACKNOWLEDGMENTS

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